A Homogeneity Grouping Technique for Geophysical Climate Models

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Abstract

A new technique for determining subgrid cell homogeneity is presented. This homogeneity testing scheme dynamically and systematically groups regions of the same characteristic types in such a way that computation is minimized by as much as an order of magnitude. Dynamically nested grids can be developed based on the resulting groups such that temporal and spatial changes can be updated and modeled with increased accuracy during a climatic simulation.

Introduction

Climate change over time scales ranging from hours to centuries are subject to land surface changes that will effect the flux exchanges between the land-surface, atmosphere, and oceans. Climate changes such as long-term droughts or temperature increases, land surface changes due to succession, as well as short duration phenomena such as fires or a diurnal vegetation kill off due to a freeze in low lying regions, will alter the surface characteristic types over time and space. Such changes need to be accounted for and updated in a concise and objective fashion.

Intuitive initializations for characteristic land surface partitioning may work for a specific class of problems; for example, where it is known that the surface characteristics are constant in time. However, time varying surface types cannot be assumed to be constant for an accurate simulation of surface processes. Furthermore, global decomposition of surface characteristics into homogenous or near homogenous groups can only be approached through a combination of objective partitioning and statistical approximations.

This note discusses an objectively derived dynamic adaptive gridding technique that depends only on the available temporally and spatially varying input data. This technique can be applied initially and used to update and reformulate grids at any specified time. A homogeneity theory is presented and an application to vegetation characteristics is provided as an example of the utility of this technique (Miller and Foster, 1991; Miller, 1993a; Miller, 1993b).

Theory

The adaptive grid requires a finite difference grid composed of cells at the land surface that maintain a match with the atmospheric mesh which provides climate forcing and feedbacks. This cell is defined here as the large scale or atmospheric model cell, AM, and may be representative of any atmospheric scale grid cell. The fine mesh land surface input data may be a description of surface vegetation types, soil textures, topography, nutrients, and/or some *effective* combination that is representative of the domain. Land surface characteristic data is inputted and updated on a much smaller scale. This cell is defined as the land surface model cell or the LSM cell. The adaptive gridding technique converts the fine-scale, possibly a heterogeneous surface of characteristics into a set of groups of homogeneous types.

The criterion by which a group is deemed homogeneous is based on a simple tolerance parameter which the user controls. The technique reduces the number of unique subregions within the AM cell on which calculations must be performed, thereby reducing the required computational work - frequently by more than an order of magnitude.

In the formulation of homogeneous groups, an intermediate set of regions are needed to keep track of the location, mass, and energy. A region consists of LSM cells, is rectangular in shape, and may range in size from a single LSM cell to the entire AM cell. All energy and mass are conserved as there is a conservation of area and thus there are no net losses or gains from the system.

Homogeneity is specified by a threshold criteria (ε) and ranges from 0.0 to 1.0. For a given ε, each region is evaluated for its percent uniformity. Percent uniformity is the frequency of occurrence of the most dominant characteristic type within the region. If the percent uniformity is equal to or greater than ε, then the region is labeled homogeneous with the dominant characteristic type. If the percent uniformity is less than ε, then the region is labeled heterogeneous and bisection occurs. The advantage of a threshold criteria is that different scales of sensitivity can be investigated and computations can be made even more economical by decreasing ε to a value where the surface response is essentially unchanged from the more accurate surface descriptions that a higher e would provide.

An initial region is defined as the AM cell, if the criteria threshold is not satisfied then heterogeneity is computed. The initial region is bisected either latitudinally or longitudinally and two newly formed regions are formed from the initial region and then each are separately evaluated for homogeneity. This procedure continues forming smaller and smaller regions, replacing a heterogeneous region, until homogeneity is obtained or regions equivalent to the LSM cell remain.

The strongest feature of this approach is the ability to investigate and determine what level of accuracy is required for a specific problem. A partial derivative of the surface function with respect to the level of accuracy may be used to determine what minimum fraction of ε is required. The following results are an application based on the homogeneity test.

Results

Figure 1 demonstrates an AM cell with a heterogeneous surface composed of 80 LSM cells with coordinates centered at 115W and 45N. Global characteristic vegetation data are used here as an application of the homogeneity test. Matthews (1983) provides data on vegetation types for a global $1^\circ \times 1^\circ$ resolution with 32 vegetation type classes. This data set acts as a static characteristic surface type input for the determination of homogeneous regions and groups that are needed to describe each large scale cell. A coarse scale $8^\circ \times 10^\circ$ resolution is chosen here for the AM cell. This resolution implies that a maximum of seven bisections can occur before the minimum $1^\circ \times 1^\circ$ LSM is reached. Below this minimum resolution, a statistical aggregation up to $1^\circ \times 1^\circ$ is required for homogeneity.

This input data indicates that are 34 short grass LSM cells that are meadows, 27 are medium grass, 12 are tall grass, 1 is tall grass with shrubs, 4 are evergreen woodland, 1 is evergreen thickets, and 1 is shrubs. The number of resulting homogeneous regions and groups are dependent on the connectedness of the LSM cells of the same type and the required threshold criteria. That is, LSM cells that have the same characteristic type and share an edge, but not strictly a corner, are considered to be of the same region. Similarly, regions with the same type and share an edge, but not strictly a corner, are of the same group.

Figure 2a indicates that for ε less than 0.425 only one region is required to meet the homogeneity test, this region consists of all 80 LSM cells. When ε equals 0.425, the homogeneity criteria is not met and an initial bisection takes place resulting in two regions and two groups, one with short grass and one with medium grass (Fig. 2b). At $\varepsilon = 0.60$, there are eight regions and four groups (Fig. 2c), ε = 0.80 results in 29 regions and six groups (Fig. 2d), ε = 0.90 results in 35 regions and eight groups (Fig. 2e), and when the threshold criteria is 1.00, 45 regions and 11 groups result (Fig. 2f). The resulting 11 groups at this finest breakdown represent separate homogeneous regions for each of which a land surface calculation can be made. Such a breakdown will vary from location to location depending on the degree of inherent homogeneity. That is, an 8° x 10° AM cell in the middle of an ocean will result in a single region and a single group regardless of the threshold criteria and an AM cell which includes coastlines and/or urban areas will require a higher number of homogeneous groups covering smaller regions (Fig. 3).

Applying this approach to global calculations is illustrated in figure 4. In this case, the characteristic vegetation data (Matthews, 1983) are used for the North American continent using 8° x 10° AM cells. It is seen from this figure that a threshold criterion of ε = 1.00 can be maintained while the actual number of homogeneous groups is approximately an order of magnitude lower than the 80 LSM cells per AM grid cell initially required. This initial application of this approach indicates the potential computational savings that will be available when using a more detailed LSM approach. The addition of ecophysiology, biogeochemistry and hydrology will add to the required amount of computational time spent at each AM subcell and the use of homogeneous subgrid regions will become increasingly important as surface models become more complex.

Conclusions

The results presented here are preliminary, however, the implications of this work extend beyond land surface/atmosphere modeling. This work is currently being expanded and implemented into a larger Earth system modeling framework. The homogeneity test is capable of decomposing and grouping data from a variety of sources and representations. The author is planning several studies utilizing this adaptive gridding technique to formulate watersheds (Miller, 1993c), clouds, and other geophysical regions where a defined homogeneity is required.

The homogeneity scheme has been rewritten in C and is now available as an object oriented code that will provide decomposition of multiple types using either bisection and quad-section. The quad-section is considered an improvement as all solutions are unique.

Acknowledgments

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References

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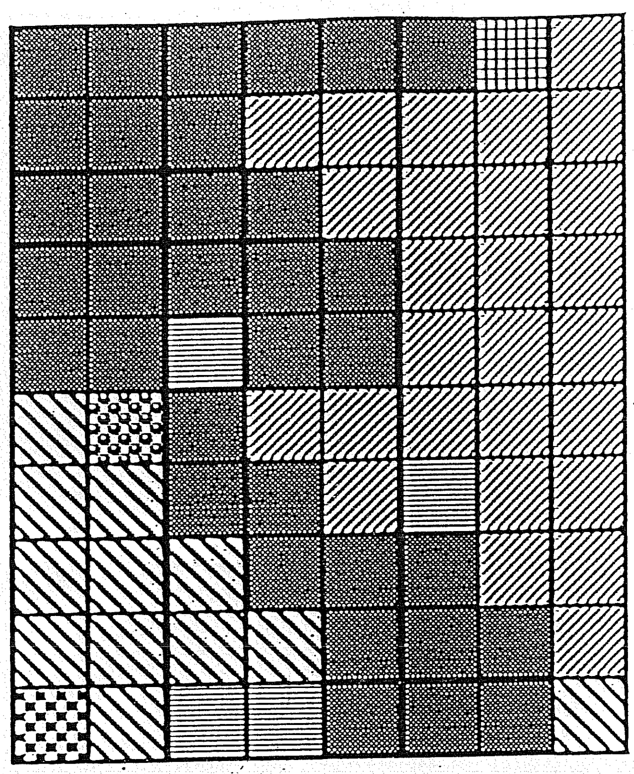
Figure Captions

Figure 1. An 8° x 10° AM cell with coordinates centered at 115W and 45N. Of the eighty 1° x 1° characteristic vegetation cells, 34 are short grass with meadows, 27 are medium grass, 12 are tall grass, 1 is tall grass with shrubs, 4 are evergreen woodland, 1 is evergreen thickets, and 1 is shrubs.

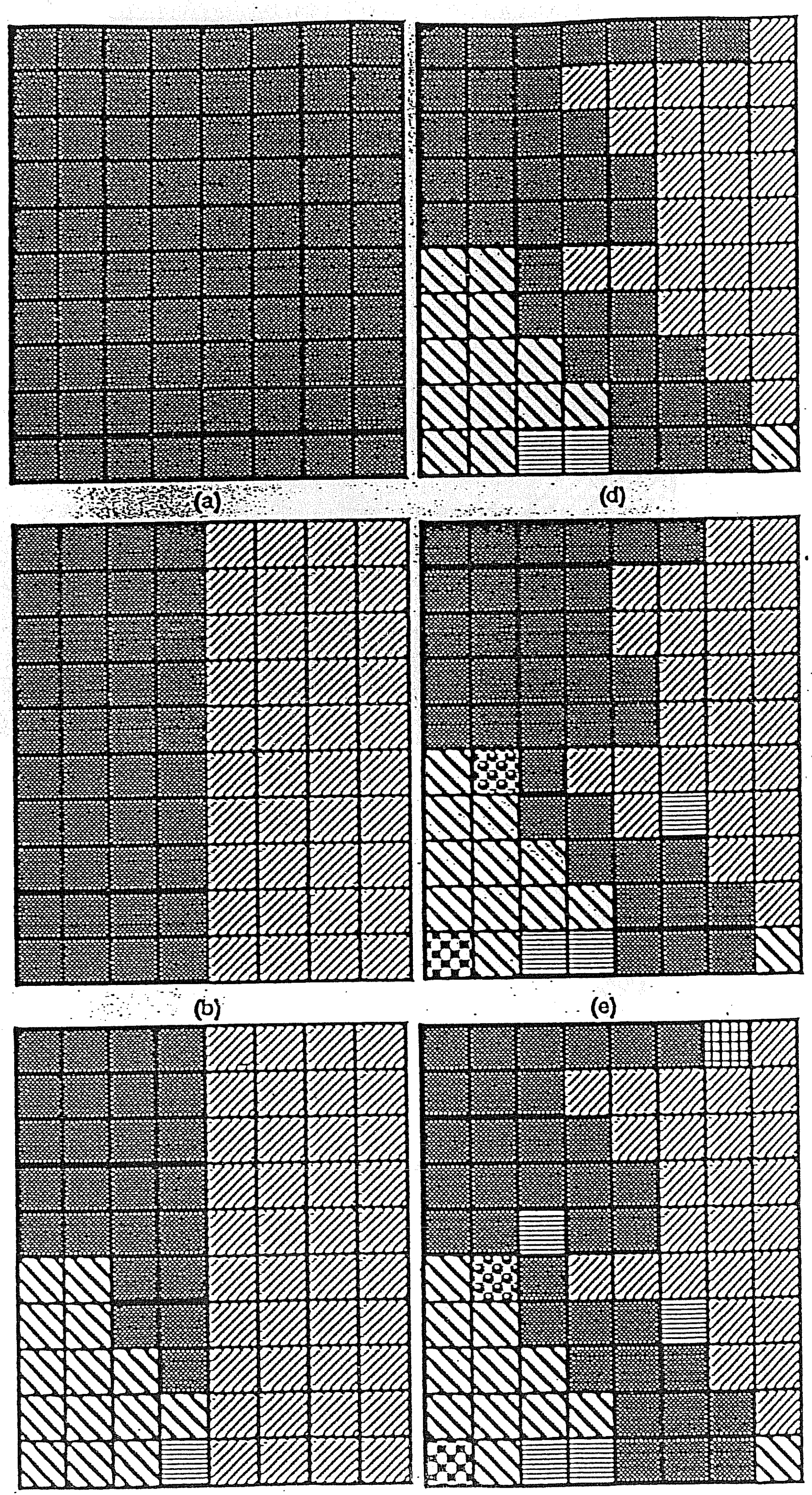
Figure 2. (a) For the threshold criteria, ε, less than 0.425, only one cell is needed to meet the homogeneity test, (b) for $\varepsilon = 0.425$, the homogeneity criteria is not met with one cell and an initial bisection takes place, resulting in 2 cells and 2 groups, one with short grass and one with medium grass, (c) for $\varepsilon = 0.60$, there need to be 8 cells and 4 groups, (d) for $\varepsilon = 0.80$, 29 cells and 6 groups result, (e) for $\varepsilon = 0.90$, 35 cells and 8 groups result, and (f) for $\varepsilon = 1.00$, 45 cells and 11 groups result.

Figure 3. Plot of number of vegetation regions against a threshold or minimum criteria, ε, for (a) mid-latitude grasslands, (b) Brazilian rain forest, (c) coastal boreal lowlands, (d) oceans.

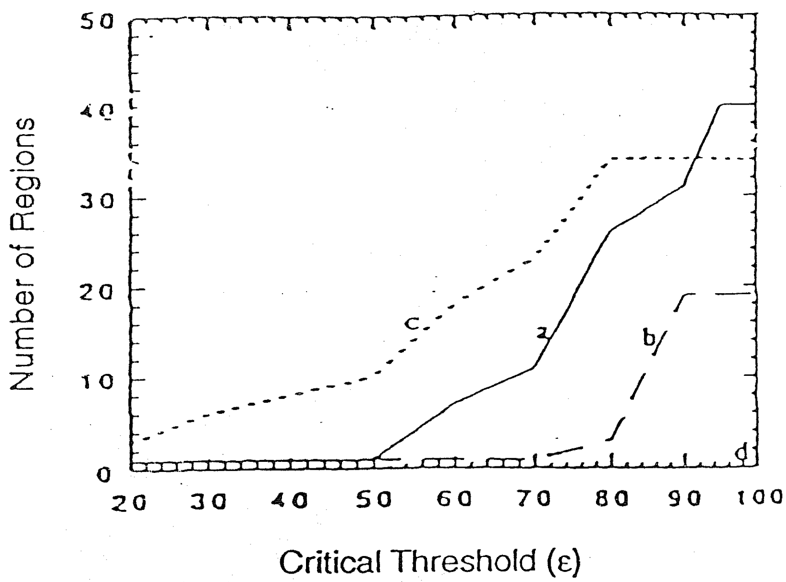
Figure 4. Matthew's (1986) characteristic vegetation is mapped over an array of 8° x 10° grid cells over the region 130W to 80W by 6N to 70N. The homogeneity forms groups that reduce the number of homogeneous regions by approximately an order of magnitude while maintaining 100% accuracy.



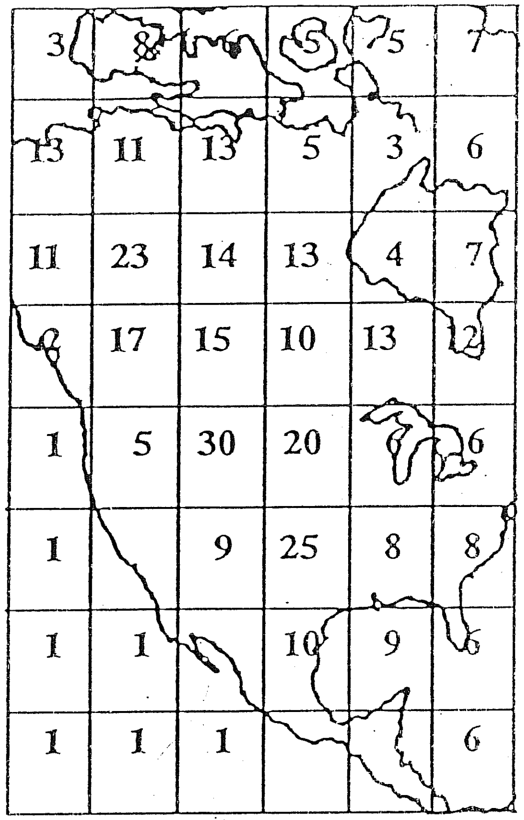
VEGETATION TYPE	NUMBER OF CELLS
Evergreen Woodland	4
Evergreen Thickets	1
Shrubs	1
Short Grass with Meadows	34
Tall Grass with Shrubs	1
Tall Grass	12
Medium Grass	27



(a) (d) (b) (e) (c) (f)



Number of Regions
Critical Threshold (ε)
50
40
30
20
10
0
20
30
40
50
60
70
80
90
100
a
b
c
d


3 8 6 5 5 7
13 11 13 5 3 6
11 23 14 13 4 7
2 17 15 10 13 12
1 5 30 20 6 6
1 9 25 8 8
1 1 10 9 6
1 1 1 6